Fatigue and Charpy Impact Characteristics of Railway Axle Material at Low Temperatures

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1. Introduction

In the past, fatigue tests in giga-cycle range was not easy. Even when a fatigue test is performed at 100 Hz, 115 days are needed to apply 10^9 loading cycles. Therefore, components under fatigue loading were designed by using an S-N (Stress amplitude-Number of cycles to failure) curve and endurance limit obtained at 2×10^6 cycles. But according to very high cycle fatigue tests [1-3], fatigue strength to failure of some materials decreases as loading cycles increase. In other words, endurance limits are not observed for those materials. With the advent of new technology, high cycle fatigue test became possible. Railway vehicles have a long lifetimes of more than 20 years. And their components are required to have long durability. The railway axle is one of the key components for structural safety of rolling stock. Failure of an axle may lead to the derailment of a vehicle, fatal accidents, property loss, etc. During the lifetime of a railway vehicle, about 3×10^6 km mileage, an axle installed in the vehicle experiences very high cycles of fatigue loading (1.0~1.2 giga cycles). Giga-cycle fatigue properties of railway axles have been studied at room temperature [4], but giga-cycle fatigue tests at low temperatures have not been carried out much until now. Due to the recent changes in the climate, railroad cars have been operating longer in the environment such as heavy snow, heavy cold, and heat waves. As a result, unexpected failures may occur and the driving conditions of the vehicle may be different. Accordingly, there is increasing interest in the mechanical properties of components in low and high temperature ranges. In this study, mechanical properties of a freight car axle at low temperatures were studied. Giga-cycle fatigue tests at +20, -30 and -60 ℃ were performed using an ultrasonic resonant fatigue tester. In addition, Charpy impact tests were carried out at low temperatures, from -60 ℃ to +60 ℃. And their fracture surfaces were examined using electronic scanning microscope.

2. Material and Methods

2.1 Fatigue specimen and tests

The chemical composition of the freight car axle was 0.35~0.48 wt. % C; 0.15~0.40 Si, 0.40~0.85 Mn, and Fe. The measured tensile strengths of three cylindrical specimens were in the range of 660-690 MPa. The specimens were extracted from a real commercial axle for railway vehicle. The surface of the specimen was polished by lapping. Ultrasonic resonant fatigue specimens were designed according to the methods presented in the literature [5,6]. To control the temperature of a chamber, liquefied nitrogen was sprayed into the chamber. **Fig. 1** shows the schematic diagram of the ultrasonic fatigue test equipment.

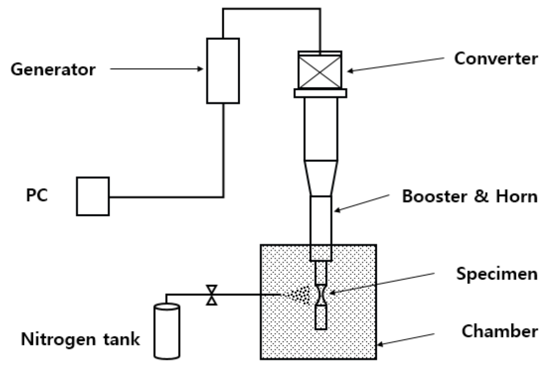

Fig. 1. Schema of the ultrasonic resonant fatigue tester.

2.2 Charpy impact specimen and tests

The Charpy impact specimens were produced according to ASTM A370 from the new axle of the actual commercial freight car. The longitudinal direction of the specimen coincides with the longitudinal direction of the axle. The specimen size was 10X10X55. The V-shaped notch was machined in the center. **Fig. 2** shows the photograph of the specimen.

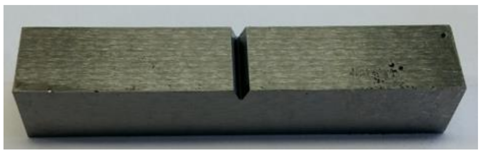

Fig. 2. Charpy impact specimen.

3. Results and Discussion

Fig. 3 shows the S-N diagram (Stress amplitude - Number of cycles to failure) at – 30 ℃**. Fig. 4** is the fracture surface. The crack occurred at the right edge and gradually progressed elliptical to some point, and then went into unstable mode. A very interesting feature is that in general, carbon steels exhibit fatigue limits at 2 million cycles, but at -30 ℃ fatigue failure occurred even over 2 million cycles.

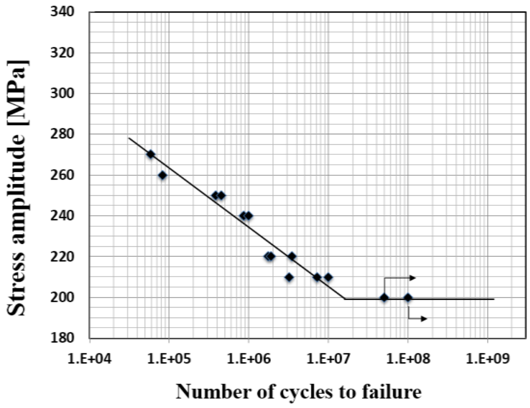

Fig**. 3.** S-N diagram at -30 ℃.

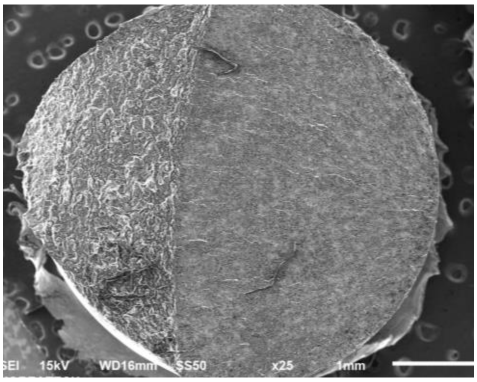

Fig. 4. Fracure surface of fatigue specimen at -30 ℃.

Fig. 5 and **Fig. 6** present the fracture surface of Charpy impact specimen at -50 ℃ and – 20 ℃, respectively. At -50 degrees, full brittle fracture occurred. At 20 degrees, 30% of the fracture surface was ductile.

Fig. 5. Fracture surface of Charpy specimen at -50 ℃.

Fig. 6. Fracture surface of Charpy specimen at +20 ℃.

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